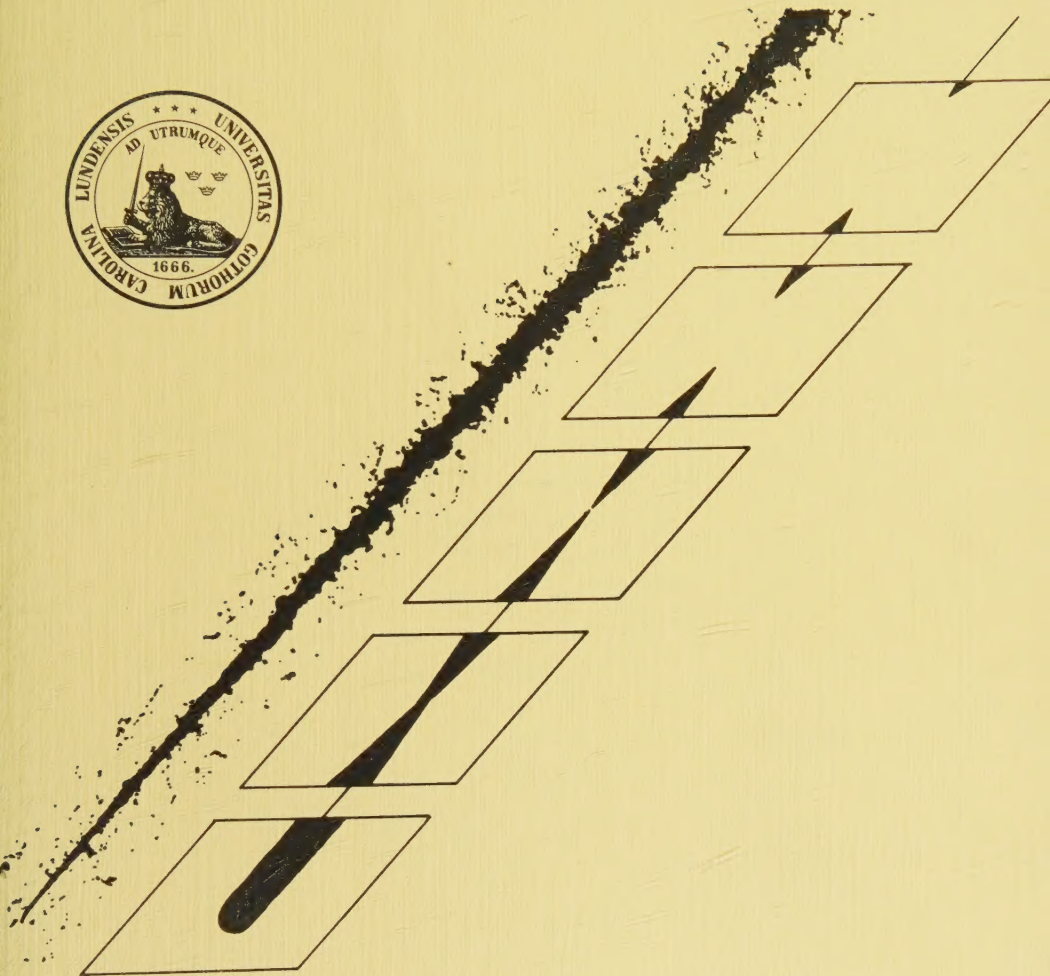




**isotopic studies on
cosmic ray iron particles
by ionization-range measurements
in visual track detectors**

Sven Hertzman

Lund

1981

COSMIC AND SUBATOMIC PHYSICS REPORT
LUIP 8007
LUNFD6/(NFFK-8007)1-11 (1980)
ISSN 0348-9329

ISOTOPIC STUDIES ON
COSMIC RAY IRON PARTICLES
BY IONIZATION-RANGE MEASUREMENTS
IN VISUAL TRACK DETECTORS

by

Sven Hertzman

FK, Sm

Akademisk avhandling som för avläggande av filosofie
doktorsexamen vid matematisk-naturvetenskapliga fakul-
teten vid universitetet i Lund kommer att offentligt
försvaras å Fysiska Institutionens föreläsningssal B
fredagen den 27 februari 1981 kl. 10.15.

Organization
LUND UNIVERSITY
Department of Physics
University of Lund
Sölvegatan 14
S-223 62 LUND, Sweden

Document name
DOCTORAL DISSERTATION

Date of issue
February 27, 1981

CODEN: LUNFD6/(NFFK-8007)1-11(1980)

Author(s)
Sven Hertzman

Sponsoring organization

Title and subtitle

Isotopic studies on cosmic ray iron particles
by ionization-range measurements in visual track detectors

Abstract

This thesis concerns a visual track detector system for isotopic studies on heavy cosmic ray particles. The isotopic composition of iron, which is essential for the model calculations of the synthesis of the nuclides in stellar interiors, has been studied by ionization-range measurements in a combination of nuclear emulsion and plastic track detectors. The parts of a particle track in a plastic detector where possible spallation reactions can not be controlled, have been replaced by emulsion pellicles. With the combined emulsion-plastic detector a good mass resolution is achieved and an accurate rejection of the particles which interact in the detector is possible.

The detector and the analysis of the emulsion part are described in detail. New knowledge of the behaviour of different plastic foils placed in contact with each other, was obtained as a by-product from the analysis of the plastic foils. The results from two balloon flights of the detector have been compared with the results from other investigations and with a Monte Carlo simulation of the isotopic composition of iron. The observed isotopic abundances indicate, that the source composition of cosmic ray iron is not very different from the isotopic composition of iron in the solar system.



Key words

galactic cosmic ray iron, isotopic composition, nuclear emulsion, cellulose-nitrate plastic

Classification system and/or index terms (if any)

LUIP 8007

Supplementary bibliographical information

Language
English

ISSN and key title

ISSN 0348-9329

ISBN

Recipient's notes

Number of pages 11

Price

Security classification

Distribution by (name and address) Sven Hertzman,
Institute of Physics, University of Lund,
Sölvegatan 14, S-223 62 LUND, Sweden.

I, the undersigned, being the copyright owner of the abstract of the above-mentioned dissertation, hereby grant to all reference sources permission to publish and disseminate the abstract of the above-mentioned dissertation.

Signature

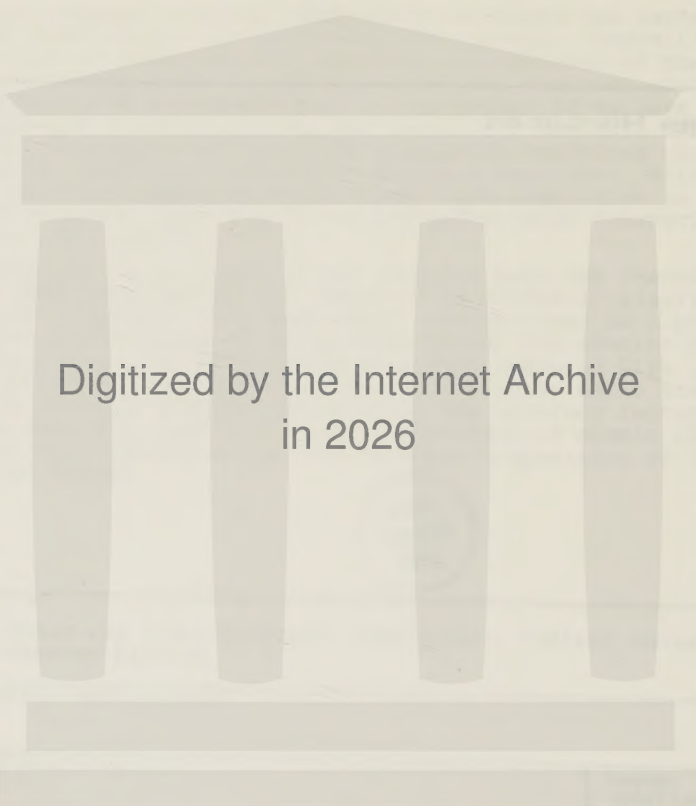
Sven Hertzman

Date

Jan 8, 1981

**isotopic studies on
cosmic ray iron particles
by ionization-range measurements
in visual track detectors**

Sven Hertzman



Digitized by the Internet Archive
in 2026

https://archive.org/details/IA41553201_0042

INTRODUCTION

In the space between the stars and the galaxies, energy can be found in a variety of forms. The interstellar space is filled with a very diluted gas, with gravitational and electromagnetic fields and with radiation of different kinds. The thin gas mainly consists of hydrogen and helium, but there are also heavier elements and molecules. The radiation is electromagnetic radiation in a broad wave-length band from radio waves to high energy γ -rays, including the isotropic 3 K blackbody radiation, which is believed to be a remnant from the creation of the Universe. It is also particle radiation, which includes high energy protons and atomic nuclei, electrons and positrons and probably also neutrinos. The particle radiation is isotropic, at least in the region of the galaxy where the solar system is situated. The particles continuously penetrate into the solar system and bombard the atmosphere of the earth. This particle radiation is usually called the cosmic radiation, or sometimes the galactic cosmic radiation, to distinguish it from the particle radiation which has its origin in the sun.

Ever since the discovery of the cosmic radiation in the beginning of our century, the main problems in the studies of the radiation have been to find its origin and the mechanism of acceleration. Owing to the absorbing effects of the atmosphere, the measurements must be carried out at very high

altitudes from balloons or in space vehicles above the atmosphere. We now know, that the source of the radiation is to be found outside our solar system. This fact gives the particles of the cosmic radiation a very unique position as the only sample of matter from astronomical objects outside the solar system which is directly available to us. Studies of the heavy nuclei in the radiation give information about the cosmic ray source and about the passage of the radiation through the space. In the last few decades it has also been clear, that the nuclei of the radiation may shed new light on the sites and the mechanisms which are involved in the synthesis of the elements in general.

Studies of the elemental composition of the cosmic radiation have indicated a general similarity to solar system composition, but also some significant differences. If we normalize the distributions to Si ($Z=14$), for example, the elements Li, Be and B ($Z=3, 4$ and 5) are overabundant in the radiation. This is also the case for the elements with atomic number $21 \leq Z \leq 25$, in the interesting charge region where Fe ($Z=26$) is by far the most abundant element. These overabundant elements have predominantly been produced in the interstellar space, when heavier nuclei as iron were split up in collisions with the interstellar matter. Other differences may possibly be related to the composition of the cosmic ray source itself or to charge dependent selection effects, which can alter the composition of the matter prior to the acceleration to cosmic ray energies.

At present, accurate measurements of the cosmic ray elemental composition have been made up through the iron group elements.

However, the elemental ratios are sensitive to several chemical separation effects which may occur after the synthesis of the elements. The original charge spectrum at the cosmic ray source can thus be changed, for example during the injection into the accelerating region, during the acceleration to cosmic ray energies or during the transport through the interstellar space. Isotopic ratios are insensitive to these chemical separation effects, and measurements of the isotopic abundances of the elements can therefore put restrictions on the possible models for the nucleosynthesis. Isotopic studies have so far mainly been limited to low atomic charges. The abundance of the radioactive isotope ^{10}Be , for example, gives information about the cosmic ray confinement time in the galaxy, the so called cosmic ray age, while the abundances of the CNO-isotopes are essential for the cosmic ray source composition. However, since the iron peak nuclei, with their high binding energy, may be considered as the final "ash" from the energy production in the stars, the isotopic composition of cosmic ray iron is of a special interest. Furthermore, the relatively large abundance of iron makes the modification by secondary processes small and the small mass difference ($\approx 2\%$) between adjacent isotopes of iron, reduces the influence of the magnetic fields on the isotopic ratios. On the other hand, the small mass difference also makes the isotopic measurements very difficult.

Several different detector techniques have been applied in these measurements, each has its advantages and its problems. In some experiments, the magnetic field of the earth has been used as a giant mass spectrometer. In other experiments, the

total energy of each registered particle is determined together with a measurement of the ionization loss or the Cerenkov light emission in thin absorbers. From these parameters the mass of the particle can be obtained, provided the parameters are known with a sufficient accuracy.

The abundance distribution of different nuclides in solar system material has been the primary source of information, on which the theories of the nucleosynthesis are based. It is now believed, that most of the present He was produced when the Universe was created. During the last 20 years there has been a general agreement, that the elements heavier than B ($Z=5$) are synthesized in a variety of processes which occur in stellar interiors and in supernova explosions. In particular, the synthesis of the nuclides in the iron group has been attributed to a process of nuclear statistical equilibrium (the so called e-process), which occurs in the interior of stars larger than about 10 solar masses. Recent model calculations of the synthesis of these nuclides, have shown the importance of the neutron excess in the particular layer in the exploding star where the nuclides are synthesized. The neutron excess is defined as $\eta = (N_n - N_p) / (N_n + N_p)$, where N_n and N_p are the abundances of neutrons and protons respectively, free or bound in nuclei. The neutron excess in the interesting layers is probably different from one supernova to another and depend on the mass of the exploding star. The original e-process model has now been modified and the statistical equilibrium depends to some degree both on the size of the star and on

the distance to the center of the star. The cosmic ray composition in the iron region should accordingly indicate in which types of supernovae the cosmic ray matter was produced and reveal the processes which are going on in the innermost regions of the stars.

CONTENTS OF THE THESIS

This thesis comprises three papers dealing with an experiment to study the isotopic composition of galactic cosmic ray iron.

I. Detection of cosmic ray iron isotopes in an emulsion-plastic system.

Published as an internal report Cosmic and Subatomic Physics Report LUIP 8004, LUNFD6/(NFFK-8004), University of Lund, registered as an abstract in International Nuclear Information System (INIS), and to be submitted to Nuclear Tracks.

(In collaboration with K. Kristiansson, K. Söderström, R. Scherzer, W. Enge and R. Beaujean).

II. Emulsion analysis on ionizing particles in a visual track detector system.

Cosmic and Subatomic Physics Report LUIP 8005, LUNFD6/(NFFK-8005), University of Lund, and registered in INIS.
(In collaboration with K. Söderström).

III. Galactic cosmic ray iron composition.

Cosmic and Subatomic Physics Report LUIP 8003, LUNFD6/(NFFK-8003), University of Lund, registered in INIS and to be submitted to Astronomy and Astrophysics.

(In collaboration with R. Scherzer, W. Enge, R. Beaujean, K. Kristiansson and K. Söderström).

Reports on this experiment were given at

- 1) The Conference of the Swedish National Committee for Physics, Gothenburg, Sweden, 1975.
- 2) The 14th International Cosmic Ray Conference, Munich, Federal Republic of Germany, 1975.
- 3) The 9th International Conference on Solid State Nuclear Track Detectors, Neuherberg/Munich, Federal Republic of Germany, 1976.
- 4) The 10th International Conference on Solid State Nuclear Track Detectors, Lyon, France, 1979.
- 5) The 16th International Cosmic Ray Conference, Kyoto, Japan, 1979.

The experiment was made in a collaboration between the emulsion detector group in Lund and the plastic track detector group in Kiel^{*)}. The detector is a new combination of two visual track detectors, nuclear emulsion and thin plastic foils. The design goal for the detector was to achieve an adequate mass resolution for the nuclides in the iron region by ionization-range measurements in the two detector parts. An accurate rejection of the particles which undergo nuclear interactions within the detector should also be possible.

^{*)} W. Enge, R. Beaujean, R. Scherzer,
Institut für Reine und Angewandte Kernphysik,
University of Kiel,
D-2300 Kiel, Federal Republic of Germany.

Charged particles, which penetrate the detectors, ionize the detector materials along the trajectories of the particles and produce so called latent tracks. A latent track is made visible by development of the photographic emulsion pellicles and by chemical etching of the plastic foils. The important parameters for the track in the studies of the isotopic composition are the residual range to the stopping point of the particle, the so called photometric track width in emulsion and the length of the formed etch cones in the plastic foils. Track widths and cone lengths depend on the charge and the velocity of the particle, while the residual range also depends on its mass. For a particle with a given charge and ionization, the residual range is proportional to the mass of the particle. If the charge of the particle is known, its mass can thus be determined by measurements of the ionization and the residual range.

Passive track detectors, like emulsion and plastic foils, have in addition to their obvious qualities also some drawbacks. In nuclear emulsion, even the loss of a single charge unit may be detected. On the other hand, the analysis is time-consuming and it is difficult to obtain a good statistical accuracy and a good charge resolution in the same experiment, since the intensity of heavy cosmic ray particles is low and the incoming cosmic rays arrive from all directions. In this experiment, the detector was exposed in two balloon flights to increase the number of particles. However, due to the limited size of the detector, necessary geometrical restrictions and some experimental problems, the number of iron nuclei in the final mass analysis was restricted to 17.

Paper I is concerned with the experimental ideas. The new detector combination and the technique to obtain the experimental cone length-range curves are discussed. When an ionizing particle penetrates a sheet of cellulose-nitrate plastic, the material is chemically altered along the particle trajectory. This can be utilized to make a track of the particle visible by a suitable chemical etching. If the particle has a sufficiently high ionization, the etching proceeds faster along the particle trajectory than on the surfaces of the sheet. Thereby a cone-pair is created. Cellulose-nitrate is a good detector for ionization measurements, since the etching rate is a very steep function of the ionization. However, there are parts of a particle track in a plastic stack where the control of possible spallation reactions is impossible. In the combined emulsion-plastic detector this problem is essentially reduced.

As a by-product from the analysis of the cone length measurements, new knowledge of the behaviour of different plastic foils, placed in contact with each other, was obtained. Sensitivity variations between cellulose-nitrate plastic foils with different camphor content can be created by a diffusion of camphor between the foils placed in contact. Camphor is used as a softening agent in various concentrations in the different foils, and it is known, that a high concentration of camphor reduces the sensitivity of cellulose-nitrate plastic.

In paper II the experimental details in the emulsion part of the detector are discussed. When a charged particle

passes through an emulsion pellicle, it interacts with the atoms of the emulsion. The charge and the velocity of the ion determine an energy dose and a dose distribution around the path of it. If the energy absorbed in a grain is sufficiently great, a silver bromide grain appears after the development and the distribution of the grains around the path forms a track. The analyses of the tracks in emulsion, including photometric track width measurements and residual range measurements to obtain the charge of the particles, are discussed in detail.

In paper III the final results of the experiment are discussed and compared with the results of other investigations on the iron isotopic abundances. There is no simple way to make an absolute calibration of the mass scale and the results are interpreted on the assumption, that the densest concentration in the mass distribution represents ^{56}Fe . Other possible assumptions do not seem to be consistent with the observed mass distribution. We compare the results with a simulated distribution, assuming solar system abundances at the cosmic ray source and an exponential path length distribution with a mean path length of 5 g/cm^2 of interstellar matter. Within the fairly large experimental errors, there are no significant differences between the two mass distributions. This experiment does not support a large excess of the isotopes ^{54}Fe and ^{58}Fe reported in some earlier investigations. It is evident, however, that new high-resolution measurements with significantly better statistics will be needed for an accurate determination of the source abundances.

ACKNOWLEDGEMENTS

To Docent Krister Kristiansson, who was my supervisor when this work started, I wish to express my sincere gratitude for introducing me to the subjects of ionizing radiation and cosmic ray physics and for his instructive guidance. I am grateful to Professor Hans Ryde and Professor Sten von Friesen for their support and interest in this experiment.

To Professor Wolfgang Enge and his group in Kiel, especially my co-authors Dr Rudolf Beaujean and Dr Reinhard Scherzer, I want to express my sincere thanks for an inspiring collaboration and a most interesting time during all my visits at Kiel University. I thoroughly enjoyed and learned from my time and work together with Dr Reinhard Scherzer, to whom I am most grateful.

I am grateful to Professor Ingvar Otterlund for his concerns during the exposure preparations, to Professor Peter Meyer at the Enrico Fermi Institute and the Office of Naval Research, Washington, D.C. for the balloon exposure of the detector. It is a pleasure for me to thank Dr Birgit Lindkvist for her guidance through innumerable details of emulsion treatment. I have had the pleasure of cooperation with Dr Kaj Söderström, who has been a most proficient colleague. I would also like to thank Docent Olev Mathiesen, Docent Sten Lindstam and Mr Uno Persson for their help at different stages of the experiment. The help, the kindness and the comradeship of all my colleagues and friends at the Department, in work shops and offices, I have very much appreciated.

I owe many thanks to my parents, who gave me the opportunity to start my studies. Last, but not least, my thanks to my beloved wife Inger, who has helped and encouraged me and shown great patience and indulgence, and to our children Henrik and Jenny, for their special kind of encouragement.

This work has been supported in part by the Swedish Natural Science Research Council and the "Kungliga Fysiografiska Sällskapet i Lund", which is gratefully acknowledged.

Department of Physics, University of Lund, Lund 1980.

